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Sandhill Wetlands Change Detection Based on Landsat Imagery.

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Sandhill Wetlands Change Detection Based on Landsat Imagery

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Thesis Acceptance

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Keep the Faith.

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Abstract

The purpose of this thesis was to determine if there had been significant changes in sandhill wetlands between the years 1972 and 1989, as determined by Landsat satellite imagery. Seven satellite images were classified and analyzed to identify wetlands in the study area and describe their characteristics. Landsat Multispectral Scanner (MSS) imagery and Thematic Mapper (TM) imagery were used as primary source data for the project. U.S. Fish and Wildlife (USFW) National Wetlands Inventory (NWI) map data and existing color infrared photography (CIR) were used to help identify wetland types from the satellite imagery. The image analysis focused on attempting to extract the most accurate wetland designation from each scene to provide the greatest quantitative and qualitative information about each wetland type. The statistical analysis described the significance of the observations, and what, if any, changes may have occurred in wetland types, over the 17 year study period. This study is especially timely as degradation of wetlands through human development, compounded by climatic fluctuations, continues in the United States.

Chapter One: Introduction

An estimated 87 million hectares (215 million acres) of wetlands were present in the contiguous United States during the time of settlement in the mid-1700's (Tiner, 1984). By the mid-1970's, less than 40 million ha (99 million acres) were left (Tiner, 1984). As the loss of wetlands continues across the United States, remaining areas of wetlands, such as those found in the Nebraska sandhills of the Great Plains, have become increasingly important. The ability to better understand and monitor changes occurring in these wetlands is important for the conservation and management of this dwindling natural resource.

The wetlands of the sandhills are a valuable resource for wildlife, as well as local and regional economies. These wetlands, located in the Central Flyway (McMurtrey et al., 1972), provide important nesting grounds and stop-over habitat for migratory waterfowl. The open water and marshy environments present desirable nesting conditions and abundant food supplies for a variety of waterfowl species (Novacek, 1989). Often these wetlands are surrounded by subirrigated meadows which provide high-quality forage for both wildlife and livestock. The sandhills are also an important ranching area for the state of Nebraska. Many of the subirrigated meadows are hayed in the summer to produce winter feed, while the upland ranges are used for summer grazing. Sandhill wetlands are also important as a recharge zone for the Ogallala Aquifer (Dreeszen, 1984). Estimates suggest that groundwater quantities in Nebraska's sandhills are approximately 1.23 trillion cubic meters (1 billion acre-feet) (Dreeszen, 1984). The Ogallala Aquifer lies beneath an area stretching from Nebraska to west-central Texas and is the single most important source of irrigation water in the Great Plains.

Many studies have been completed to inventory or to investigate different techniques to map sandhill wetlands (Work and Gilmer, 1976; Rundquist and Linden, 1979; Gilmer et al., 1980; Gilbert et al., 1980; Turner and Rundquist, 1980; Ernst-Dottavio, 1981; Christian, 1982; Buckwalter, 1983; Koeln et al., 1986, Jacobson et al., 1987; Rundquist et al., 1987), but few have focused on the temporal dynamics of these wetlands. Remote sensing has long been accepted as a wetlands mapping tool, involving the use of visual, photographic, or satellite gathered data. Since 1972, regularly gathered satellite data have been available from the Landsat program, providing approximately twenty years of imagery from which wetland information can be gathered and analyzed. Very little is known about how the wetlands of the sandhills have changed, or if there is an indication of a trend in wetland conditions. An investigation of the changes that have taken place in sandhill wetlands, is both important and timely, as humans have discovered the dramatic impact we have had on the environment over the last century.

The purpose of this study was to use satellite imagery to determine if significant changes occurred in sandhill wetlands between the years 1972 and 1989. Landsat Multispectral Scanner (MSS) imagery and Thematic Mapper (TM) imagery were used as source data for the project. U.S. Fish and Wildlife (USFW) National Wetlands Inventory (NWI) map data and color-infrared (CIR) photography, were used as reference data to help identify and verify wetland types from the satellite data. The resulting information was used to identify spatial changes, and changes in wetland types, over the 17 year period.

THE SANDHILLS

The sandhills region extends over approximately 50,000 square kilometers (19,300 square miles) of the central Great Plains, lying mostly within north-central Nebraska (Keech and Bentall, 1971) (Figure 1). Dune formation occurred during several eolian events within the last 8,000 years (Swinehart and Diffendal, 1989). Average dune elevations range from 1,295 meters (4,250 ft.) in western sections to 670 meters (2,200 ft.) in the east, while dune heights ranges from about 30 meters (100 ft.) to about 91 meters (300 ft.) (Keech and Bentall, 1971).

Though predominantly covered with vegetation, the sandhills soils are relatively thin. These soils have an A horizon that typically measures less than 12 cm (4.7 in.) in thickness with no B horizon, and an abrupt transition to the fine grained, sand parent material of the C horizon (Kuzila, 1989). Consequently, when the vegetative cover is lost, wind erosion is a major problem with these soils.

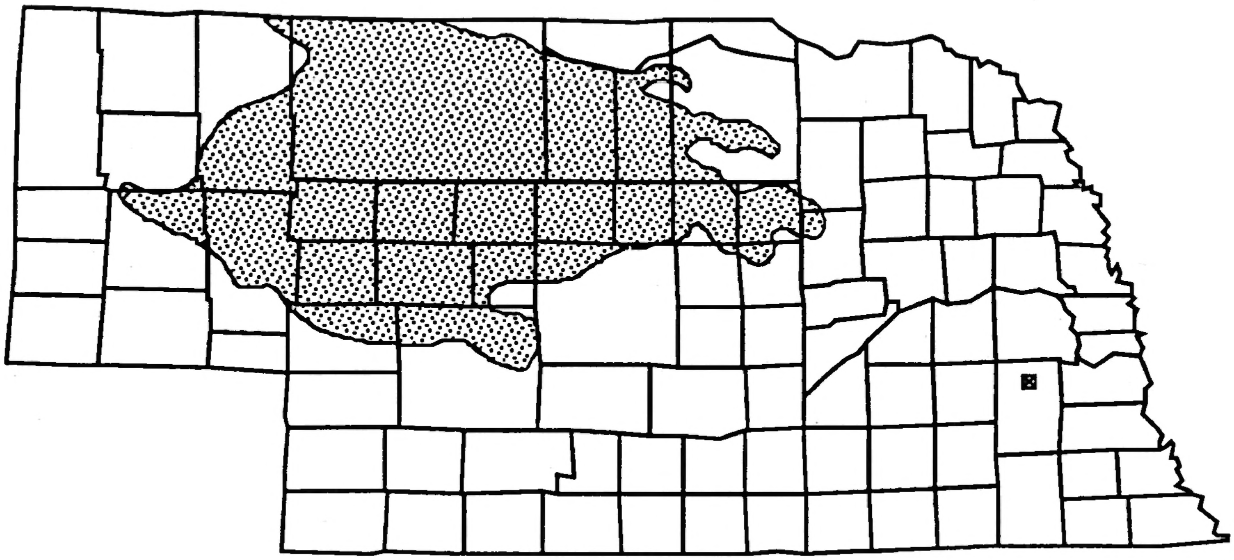

Figure 1. General location of the sandhills in the state of Nebraska. (not to scale)

Below the soils of the sandhills lies what may be the single most important factor for life in the region. Highly permeable soils that limit surface runoff, promote the recharge of the groundwater supply beneath the sandhills. A very gently sloping, impermeable bedrock layer below the dunes, traps this groundwater and forms the High Plains Aquifer system, of which the most important is the Ogallala Aquifer (Bleed, 1989). In this rolling terrain, depth to groundwater varies. On dune crests, the water table may be up to 140 m (300 feet) below the surface, but in some inter dunal valleys the water table actually intersects the surface, forming numerous marshes and lakes (Bleed, 1989).

The region falls within the climate category continental sub-humid, and experiences cold winters and hot summers with recorded temperature extremes from -40.0 to +43.3 degrees Celsius (-40 to +110 degrees

Fahrenheit), with an annual mean of +8.9 degrees C (+48 degrees F) (Keech and Bentall, 1971). Approximately 75% of annual precipitation falls between the months of April and September (Wilhite and Hubbard, 1989). Total precipitation ranges from 406.4 millimeters (16 inches) in the west to about 609.6 mm (24 in.) in the eastern areas (Keech and Bentall, 1971).

The flora of the sandhills is comprised of a wide variety of plant communities dominated by "sandhills prairie," which is a type of mixed-grass prairie including a large number of xerophytic psammophytes (Novacek, 1989). Vegetation is dictated primarily by the proximity of ground water to the surface. In areas where the distance to groundwater is substantial, soil texture dictates vegetation (Novacek, 1989). More expansive discussions on the vegetation of the sandhills can be found in the following: Rydberg, 1895; Pool, 1914; Frolik and Keim, 1933; McAtee, 1941; Tolstead, 1942; Ehlers et al., 1952; Sather, 1958; Brouse and Burzlaff 1968; Mahoney, 1977; Gilbert, 1980; Barnes and Harrison, 1982.

PREVIOUS REMOTE SENSING WETLAND STUDIES IN THE SANDHILLS

The need to study the conditions of wetlands in the sandhills was first recognized by the United States Fish and Wildlife Service (USFW) in the 1950's. A survey of the nation's wetlands by the USFW included the sandhills, however, the information gathered for this region was not extensive. In the survey of the sandhills, visual inspection was made of wetlands that were within one-eighth mile of roadways. This was done for a total of 976 "driven" transect miles, constituting a one percent sample of the sandhills area. Projections of wetland acreages were made from this information (U.S. Department of the Interior, 1955).

In 1958, the Central Flyway Waterfowl Council and Technical Committee, suggested a need to view wetlands as vital habitat for the continued production of waterfowl in the Great Plains (McMurtrey et al., 1972). They suggested that wetlands should be considered as valuable ecological habitat and not merely as lands that are too wet for agriculture. The Nebraska Game and Parks Commission responded by initiating a survey of wetland habitats from 1962 through 1968. For this survey, black and white, Soil Conservation Service (SCS) air-photos were analyzed to determine wetland classes and area coverage, with field measurements gathered to maintain accuracy and consistency. The 1972 results for this study showed that there were originally 74,216 ha (183,391 acres) of wetlands in the sandhills (McMurtrey et al., 1972), and by the 1970's, the amount of wetlands had been reduced to 62,880 ha (155,379 acres). However, the 1972 results did not include "extensive" acreages of subirrigated meadows found in the eastern part of the sandhills, due to a problem in defining meadow boundaries (McMurtrey et al., 1972).

The first attempt to utilize satellite imagery in assessing wetland conditions in the sandhills, was a Nebraska wetlands inventory begun in 1974 (Seevers et al., 1975). In a project funded by the Nebraska Game and Parks Commission and the National Aeronautic and Space Administration (NASA), all wetlands 10 acres or larger were identified as one of three classes: open water, marshes, or subirrigated meadows. Positive prints of the imagery were visually examined to delineate wetlands. Spatial characteristics of the wetlands were mapped at 1:250,000. However, in the study, area measurements were not tabulated, which prohibits direct comparison of results with other surveys.

The successful demonstration of the use of satellite imagery for wetland studies led the Omaha District, U.S. Army Corps of Engineers, to pursue an inventory of the wetlands in the Upper Missouri River Basin (approximately 1,139,600 sq. km (or 440,000 sq. miles) of the northern Great Plains) through digital analysis of Landsat Multispectral Scanner (MSS) satellite imagery. Wetland maps were generated designating open water, marsh, and subirrigated meadow, and were designed to overlay USGS, 71/2 minute quadrangles. This inventory determined that as of 1980, there were 453,636 ha (1,120,954 acres) of subirrigated meadow, 26,111 ha (64,521 acres) of marsh, and 45,518 ha (112,478 acres) of open water in the sandhills (Turner and Rundquist, 1980).

Beginning in 1979, the USFW began the National Wetlands Inventory, an extensive remote sensing inventory of the nation's wetlands. The project was designed to describe wetland conditions based upon their ecological characteristics (Wilen and Tiner, 1989). The USFW, selected color infrared photography, rather than satellite imagery, to obtain the classification detail and wetland discrimination, within the accuracy requirements desired. Wetlands were classified according the system developed by Cowardin et al. (1979), and mapped to 1:24,000 scale maps. As of 1993, the contiguous 48 states of the United States have been mapped and work is proceeding to digitize the wetland, map data. As of this data, the sandhills had not been completely digitized and no area totals have been compiled.

Other remote sensing wetland studies that have utilized satellite imagery as source data include prairie-pond inventories (Work and Gilmer, 1976); testing Landsat MSS data for classifying Nebraska sandhills wetlands (Rundquist and Linden, 1979); comparison of remote sensing and field evaluation of sandhill wetlands (Gilbert et al., 1980); measuring lake surface area (Buckwalter, 1983; Rundquist et al., 1987); and Ducks Unlimited's Thematic Mapper wetland inventory (Koeln et al., 1986). In each case, the use of remotely sensed data provided the means to investigate areas of extensive size that might otherwise be difficult to reach or measure on the ground. In each investigation, satellite imagery was deemed to be the most useful and cost effective tool for gathering information about wetlands.

Rundquist (1984), summarized previous sandhills wetland inventories that utilized visual, air-photo, color-infrared, and satellite remote sensing data. His report indicated an inability to directly compare the results of individual surveys, due primarily to differing "wetland" definitions. In addition, he suggests that some of the basic problems in assessing wetland changes over time are inconsistent wetland classifications and varying techniques of data collection. A combination of these detrimental factors made determination of any wetland trends from previous studies, extremely difficult (Rundquist, 1984).

Chapter Two: Methodology

STUDY AREA

The area selected for this study was the Willow Lake, United States Geological Survey (USGS) 7.5 minute topographic quadrangle (N 42° 30' 00", W 100° 30' 00"), which includes an area in and around the Valentine National Wildlife Refuge (VNWR). This area was selected primarily because it contains the various types of wetlands found in the sandhills of north-central Nebraska and because of existing, available satellite imagery and color infrared photography of the area. Figure 2. illustrates the general location of the Willow Lake quadrangle in reference to the wildlife refuge.

Novacek (1989), in a discussion of the need for further research of sandhill wetlands, recommended the VNWR as a likely site because of the information (e.g., climate, hydrological, wildlife, management practices, etc.) that is gathered there on a routine basis. Such information, if appropriate, could be available for correlation with ongoing or future research projects.

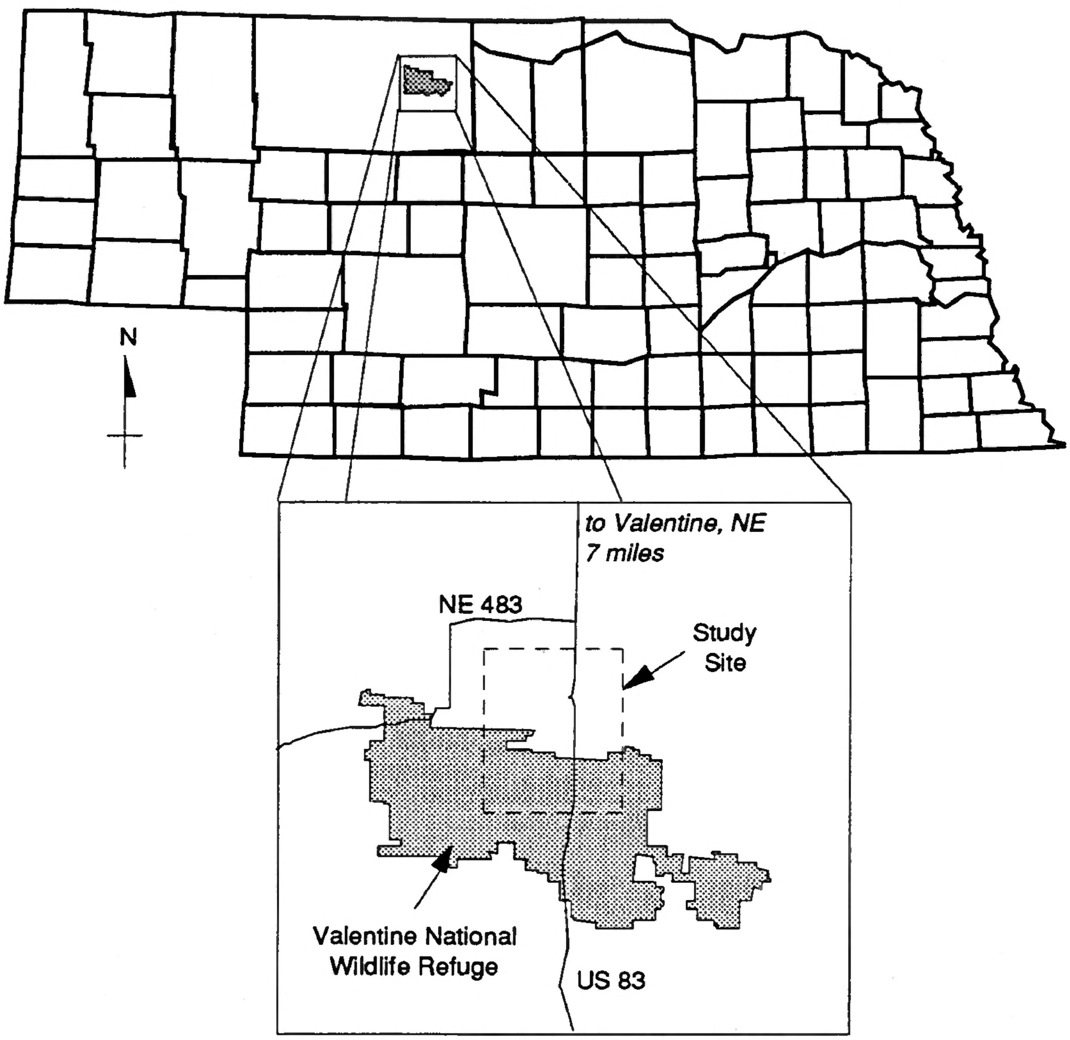

Figure 2. General location of the Willow Lake USGS quad, in relation to the VNWR and the state of Nebraska. (not to scale)

SATELLITE IMAGERY

The Landsat satellite program began collecting data in the summer of 1972 with the launch of Landsat 1 (then ERTS-1). The early Multispectral

Scanner (MSS) satellites (Landsats 1-3) orbited the earth at approximately 900 km (560 miles) in altitude, at an angle of 9 degrees from the North and South poles (Lillesand and Kiefer, 1987). These satellites scanned an area 185 km (115 miles) wide with a surface resolution of approximately 79 m x 79 m, in 4 spectral bands (Table 1.). The orbital velocity of the satellite allowed for 14 orbits each day and resulted in a return interval to any point on the earth every 18 days.

Table 1. Spectral Sensitivity of Landsat Satellite Sensors (Jensen, 1986).

MSS (Multispectral Scanner)			TM (Thematic Mapper)		
Band	Wavelength (in microns)	Spectral Sensitivity	Band	Wavelength (in microns)	Spectral Sensitivity
4	0.5-0.6	visible green	1	0.45-0.52	visible blue
5	0.6-0.7	visible red	2	0.52-0.60	visible green
6	0.7-0.8	near ir	3	0.63-0.69	visible red
7	0.8-1.1	near ir	4	0.76-0.90	near ir
			5	1.00-1.30	middle ir
			6	10.40-12.50	thermal ir
			7	2.08-2.35	middle ir

In July of 1982, the Thematic Mapper (TM) satellite series was begun with the launch of Landsat 4. This platform orbited the earth at 705 km (438 miles), completing 14.5 orbits per day (Lillesand and Kiefer, 1987). This lower orbit allows for a 16 day cycle of surface coverage with a surface resolution of 30 m x 30 m in 6 reflective bands, plus a 120 m x 120 m thermal band (Table 1.). The most important advance of the TM series was the addition of two mid-infrared bands that focus on moisture content of target bodies, and the increased surface spatial resolution, providing more discernibility of surface features from the satellite's data.

Data used for this study consisted of Landsat MSS and TM imagery. MSS imagery was obtained for August 17, 1972; July 15, 1975; July 26, 1978; September 5, 1979; and July 15, 1982. TM imagery was obtained for July 8, 1984, and July 24, 1989. Dataset selection was based on overcoming a limited availability of historical imagery but also took into account the following considerations (not in any particular order): a) peak growing season of marsh plants, late spring and early summer (Rundquist and Linden, 1979); b) availability of cloud-free imagery of the study area; c) consistency of time intervals between datasets; and d) similarity in time of year for each image. All of the data were obtained from the Earth Observation Satellite Company (EOSAT), which is the current distributor of Landsat data.

The time frame for this study was 17 years, from 1972 to 1989. This time frame was selected to investigate sandhill wetlands over the longest time period possible with satellite data. Doing so required analyzing and comparing imagery with different spatial and spectral characteristics, but in order to extract a long-term trend it was deemed necessary. The image processing and classification steps were designed to attempt to resolve these differences, as much as possible.

PREPROCESSING

The quality of MSS data sometimes varies from scene to scene and from satellite to satellite (Rohde, 1978). Examination of the scene quality is necessary before beginning a satellite mapping project. Upon evaluation of the data acquired for this study, several pre-analysis, processing steps were required. Radiometric corrections were applied to the MSS data that included deskewing and destriping (Lillesand and Kiefer, 1987). Typically, these two error types have been associated with the earlier Landsat MSS images and have been systematically corrected with the newer Landsat TM satellites. No corrections were necessary for the TM data.

The deskewing problem results from a systematic distortion brought about by the rotation of the earth while the satellite is scanning the surface (Lillesand and Kiefer, 1987). The result is a slight shifting of the scanned lines and can easily be corrected. The deskewing process simply accounts for this shift, re-samples the data, and repositions the scan lines to their proper earth-relative positions (ERDAS, 1990). The ERDAS DESKEW procedure was only required on the 1982 MSS scene, the other MSS scenes had been acquired from the vendor with this correction applied.

Striping refers to the systematic introduction of signal noise due to miscalibration of the satellite sensors, particularly on the earlier Landsat satellites. This effect manifests itself as lines of data that appear to be scaled differently than the surrounding lines of data. This problem may occur in any or all of the four spectral bands of MSS data. Algorithms have been developed to remove this problem by re-sampling the entire image and creating a new scaling factor for the histogram of the stripe lines. The stripe lines are then corrected, based on the characteristics of the other good lines of data (ERDAS, 1990). The ERDAS DESTRIP program was applied to each of the five MSS data sets.

The next preprocessing step was to match the spatial resolution of the two data types and geo-rectify each dataset. The TM data has a cell size of approximately 30 m x 30 m, while the MSS cell size is approximately 80 m x 80 m. In order to directly compare the results from the MSS and TM data types, each dataset was re-sampled to a 40 m x 40 m cell size. This cell size was selected somewhat arbitrarily, to minimize the spatial degradation of the TM data and also to attempt to increase the spatial definition of the MSS data, without going beyond a cell size less than one-quarter of the original cell. To accomplish this, all six datasets were geo-referenced to a Universal Transverse Mercator projection (UTM) with a specified output cell size of 40 m. Sixteen control points were gathered for each dataset, with control based on a 1:24,000 scale United States Geological Survey (USGS) quadrangle, and were used to calculate a second order transformation with sub-pixel accuracy to the specified projection grid. The ERDAS commands GCP, COORDN, and NRECTIFY were used, in sequence, for this procedure (ERDAS, 1990).

The final preprocessing step was to produce a Normalized Difference Vegetation Index (NDVI) transformation (Rouse et al., 1973) for the MSS data. The NDVI transformation was demonstrated as a means to measure the presence and vigor of vegetation and can be correlated with several ecological variables (Cihlar et al., 1991) by using a ratio of MSS band 7 to band 5. The ratio compares the chlorophyll emission detection of band 7 against the chlorophyll absorption detection of band 5.

$$\mathrm{NDVI} = (B7 - B5)/(B7 + B5)$$

The NDVI transformation data was added to each MSS dataset to compensate for a spectral confusion between open water and upland area. The need for the NDVI was determined from initial classification attempts for the project, using the four MSS bands in an unsupervised classification of wetland types. The ERDAS program ISODATA was used in several attempts, applying a varying number of clusters ranging from 30 to 100, sampling each cell, with confidence thresholds from 95% to 100%. In each case the results seemed to indicate a tendency to misrepresent some open water areas as hillside-upland signatures in several of the datasets, based upon comparison with CIR and NWI map information.

Interpretation of the 1974, 1979, and 1980 CIR photography, suggested this was the result of higher alkalinity levels in some of the lakes and ponds of the area. Spectrally, this confusion showed up in the two visible bands (0.5-0.6 microns and 0.6-0.7 microns) and also in the first IR band (0.7 - 0.8 microns) with much higher than normal reflectance values for open water areas. The NDVI was added to the original four MSS bands and classification tests were again run in the same manner. This would leave the original information inherent in each band, intact, while the NDVI would add to the discernibility of open water and the sub-irrigated meadow vs. hillside-upland transition areas. The results were positive, showing little sign of the open water and upland confusion.

The two TM datasets that were used in this study required no additional preprocessing, beyond the geo-rectification and re-sampling of the data to 40 m cells. After reviewing the wetland mapping work done by Ducks Unlimited (Koeln et al., 1986), it was determined that the TM data would provide adequate information to delineate wetlands in the study area. The methodology that they used was similar enough to the approach used in this study, and had been proven successful in delineating wetland types. Figures 3 through 9 represent each of the datasets that were used in the wetland classification.

Figure 3. 1972 Willow Lake MSS data, 7-5-4 (rgb).

Figure 4. 1975 Willow Lake MSS data, 7-5-4 (rgb).

Figure 5. 1978 Willow Lake MSS data, 7-5-4 (rgb).

Figure 6. 1979 Willow Lake MSS data, 7-5-4 (rgb).

Figure 7. 1982 Willow Lake MSS data, 7-5-4 (rgb).

Figure 8. 1984 Willow Lake TM data, 4-3-2 (rgb).

Figure 9. 1989 Willow Lake TM data, 4-3-2 (rgb).

WETLAND CLASSIFICATION

Once the datasets were ready for evaluation, a classification methodology had to be developed to provide the best possible wetland classification over the time period and across the different data types. Because a field check of historic datasets was not possible, the process needed to account for variations in the spectral representation of wetlands and also avoid analyst pre-conceptions of wetland locations and conditions.

Designation and delineation of the wetlands were performed with a two-step computerized classification process. The procedure used for identifying wetland classes was based upon an unsupervised classification algorithm, ISODATA, in ERDAS. In this algorithm, clusters are calculated based upon the statistical separability of the image information. The algorithm repeatedly analyzes the spectral statistics for each band of each dataset to separate the different signatures into clusters. This is done by refining and recalculating the mean from repeated passes over the input data, while approaching a user defined statistical confidence threshold (ERDAS, 1990).

Using this approach avoided analyst bias and also made more straightforward the classification procedures. The steps that were used for the classification were largely developed from experimentation to overcome the short-comings of the spectral information in the MSS data. Consequently, an iterative, or stratifying, procedure was adopted to produce the wetland classification. This helped focus the classification process on the spectral data ranges that represented wetlands, by removing the areas known to be non-wetland. The parameters used in the classification steps were determined from the evaluation of preliminary classification results as compared to CIR photography and NWI map data. The number of clusters used was determined by the need to accommodate the varied spectral signatures of the study area and the need for practicality. The use of less than 60 clusters seemed unable to separate the subtle variations in the spectral signature of the wetlands, while more than 60 clusters made analyst interpretation difficult and did not appear to clarify the distinction of wetland types. The high confidence thresholds applied to the classifications were used to refine the clusters to the highest amount of separability possible, again in consideration of the subtle spectral changes of the wetlands.

The initial phase of the classification was to separate all potential wetland areas from the surrounding upland hills, thereby removing non-wetland areas from the analysis. This was accomplished by running ISODATA with 60 clusters, sampling each pixel, using a 99% confidence threshold. The results were then graphically overlaid on top of the original scene to select the non-wetland areas. The decision process was based upon the spectral separateness and spatial consistency of a cluster, relative to visual interpretation of the original satellite data, 1974, 1979, and 1980 CIR photography, and 1982 NWI map data. Mixed clusters were categorized based upon majority of coverage.

The clusters selected were then recoded to create a mask, but before the original data was masked out, a process had to be applied to remove gaps created by mixed clusters left out of the selected area. A one-cell buffer was added to ensure complete selection of potential wetland areas. This was accomplished using the ERDAS command SEARCH (ERDAS, 1990). Some remaining gaps still persisted, so a filter was applied to help remove interior holes in the area coverage of the mask, this was done using the ERDAS command SCAN with a 3x3, doughnut kernel and a majority analysis using a threshold of 5.

Once the mask was created, the analysis scene was then masked to get only the areas of interest, or in this case, the potential wetland areas. The resulting image data was then classified with ISODATA, using 60 clusters again, sampling each cell, with a confidence threshold of 100%. The output file of this classification was then graphically overlaid on top of the original scene to evaluate the clusters and identify with which class, each should be associated. After each cluster was identified, each was recoded to create a five-class raster file from which wetland results were derived, four wetland classes and one non-wetland class.

The results were graphically overlaid on top of the original scene to select wetland classes. The decision process was again based upon the spectral separateness and spatial consistency of each cluster, relative to manual interpretation of the original satellite data, 1974, 1979, and 1980 CIR photography, and 1982 NWI map data. Mixed clusters were categorized based upon majority of coverage and at this point were separated from the wetland classes (including the non-wetland class). The mixed classes were then used to mask the analysis dataset and a third classification was run on only these areas, using ISODATA with 30 clusters, sampling each cell, with a 100% confidence threshold. The results from the mixed dataset were then overlaid on top of the original data to classify the clusters according to manual interpretation of the original image, 1974, 1979, and 1980 CIR photography, and 1982 NWI map data.

The results from the second classification were then merged with the results from the analysis of mixed data, to build the wetland classification. The final mapping results were developed by applying a 1.44 hectare minimum mapping unit to the data. This was done to establish better confidence in the overall results, since the MSS data were resampled to a considerably smaller cell size. The resampling to a 40 meter cell was performed to "extract" more interpretability from the 80 meter cells. By applying this minimum mapping unit, it reduced the uncertainty of the results derived from the resampled data

The four classes that were used to delineate wetlands in this study were derived from a combination between two principle satellite wetland mapping methodologies. For MSS data, the classification scheme of Seevers et al. (1975), Rundquist and Linden (1979), and Turner and Rundquist (1980) was considered. In each case, the focus was on three classes for wetlands, best summarized by the definitions used in the 1980 "Wetland Inventory of the Omaha District" (Turner and Rundquist, 1980):

> <u>Open Water:</u>
> All natural or man-made lakes, ponds, and reservoirs. Rivers or streams with a sufficiently large channel so as to be discernible on the Landsat imagery are also included as fresh open water (or inland saline water in the case of alkali lakes).
>
> <u>Marshes:</u>
> Any potential wetland containing quiescent water holding emergent or floating vegetation; typically grasses, bulrushes (including the hard-stemmed variety), spikerushes, cattails, arrowheads, whitetop, wild rice, reeds, sago, pondweed, and other less-common species. This class includes deep marshes and shallow marshes as well as the inland saline marsh.
>
> <u>Subirrigated Meadows:</u>
> Those areas in the Nebraska Sandhills in which the plants derive their moisture directly from the water table instead of

from vadose water. Vegetation in these wet meadows is made up largely of grasses and sedges with some rushes and other broadleaf plants. Quiescent water located within a subirrigated meadow is mapped as open water.

For TM data, thc classification scheme used by Ducks Unlimited for their wetland mapping project (Koeln et al., 1986) was considered. The wetland classes used were defined as:

Open Water:
A body of water with a surface clear of wetland vegetation, sufficient enough to respond spectrally as water (inferred).

Deep Marsh:
Basically defined as emergent wetland vegetation growing in one foot or more of water.

Shallow Marsh:
Emergent wetland vegetation growing in less that one foot of water.

For the purpose of this study, the classification scheme outlined by Duck's Unlimited was attempted, with the addition of Turner and Rundquist's (1980) "Subirrigated Meadow" class. The final results of the study, however, were necessarily reported in three classes: "Open Water", "Marsh", and "Subirrigated Meadow". The reason for this modification was due to the assessment of classification accuracy from the "Control" data of 1979.

ACCURACY ASSESSMENT

The 1979 MSS scene was used as a control dataset to test the classification methodology developed for this study. Large scale (1:24,000) color-infrared photography that coincided with the 1979 MSS scene was available from a previous wetland study. The 1979 scene was classified using the same methods as the other six scenes, and the results were compared with manual interpretation of the CIR photos. To test the classification, 80 control points were selected that compared the wetland classification of the satellite imagery with that derived from photo-interpretation of the CIR photography. The accuracy recorded for the four wetland classes indicated good results for the Open Water and the Wet Meadow classes, but rather poor results in distinguishing between the Deep Marsh and Shallow Marsh classes. Upon close scrutiny of the error matrix it was determined that better overall results would be obtained by combining the two marsh categories into a single Marsh class. Figure 10 indicates the results of the test, after combining the two marsh classes.

The results listed in Figure 10 indicate an overall accuracy of 85%. The column of Producers Accuracy indicates omission errors, and implies the probability of correct classification of each class, compared to the reference data (Congalton, 1991). The Users Accuracy indicates commission errors, and indicates how successful the classification was in delineating each class (Congalton, 1991). The results indicate that there was some confusion in discriminating Marsh from the other two classes.

The test was designed to focus the evaluation on the MSS data, with the assumption that the MSS data would be the most likely to provide erroneous classification results. The test indicated acceptable results for mapping wetlands with satellite data, using this methodology. The accuracy results for the Marsh class suggested it was the most difficult class to correctly identify. This was probably due to the difficulty in defining the Wet Meadow-Marsh boundary.

Reference Data

Classified Data

	Open Water	Marsh	Wet Meadow	Total
Open Water	14	1	1	16
Marsh	4	11	2	17
Wet Meadow	0	4	43	47
Total	18	16	46	80

	Producers Accuracy	Users Accuracy	Overall Classification Accuracy
Open Water	77.8%	87.5%	
Marsh	68.8%	64.7%	85%
Wet Meadow	93.5%	91.5%	

Figure 10. Accuracy assessment of wetland classification, 1979 MSS data.

Varying alkalinity levels, as determined from CIR photography, in the area lakes and ponds added small areas of confusion to the shoreline transition areas. This probably accounts for most of the error in the accuracy assessment for Open Water. As indicated earlier, the MSS sensors appeared to sense surrounding Non-wetland or upland areas similarly as it saw some alkaline lakes. The NDVI transformation seemed to not have offset enough of this confusion.

Change detection was performed by analyzing the total measured area for each dataset and by applying a crosstabulation analysis to sequential sample pairs (i.e., 1972 vs. 1975, 1975 vs. 1978, etc.). Statistics from the area totals were used to indicate the trend of changes that occurred over the study period. The crosstabulation directly compared each dataset, providing information about both the quality and quantity of wetland changes that occurred between sample periods. Each dataset was tested on a pixel by pixel basis, comparing the class designations. In addition, a measure of persistence was determined in the crosstabulation analysis for each class, from each sample pair. Interpretation of this measure indicates the amount of inconsistency each class exhibits over time.

Chapter Three: Results and Discussion

A total of seven data samples, derived from satellite imagery, were gathered for the study, at the indicated times. The sample dates were selected to maximize the temporal coverage of the study area and provide quality data for analysis. As explained previously, procedures were presented by which wetland conditions could be identified and measured from Landsat MSS and TM imagery. Four classes were delineated, three wetland classes and one non-wetland class, to indicate how much change occurred in wetland resources, in the study area. From the area measurements, it was also possible to analyze the types of changes that took place by crosstabulation analysis for each sequential, sample pair.

The determination of whether or not significant changes in wetland conditions were detected from the analysis of satellite data, was based upon the evaluation of the overall sample measurements. The characterization of how the wetlands of the study area changed was developed from a crosstabulation analysis of each sequential sample pair.

RESULTS

The following figures (11 through 17) represent the results of the wetland mapping for the Willow Lake quad, study area. The color codes are as follows:

BLUE = Open Water
RED = Marsh
YELLOW = Wet Meadow
GRAY = Non-wetland.

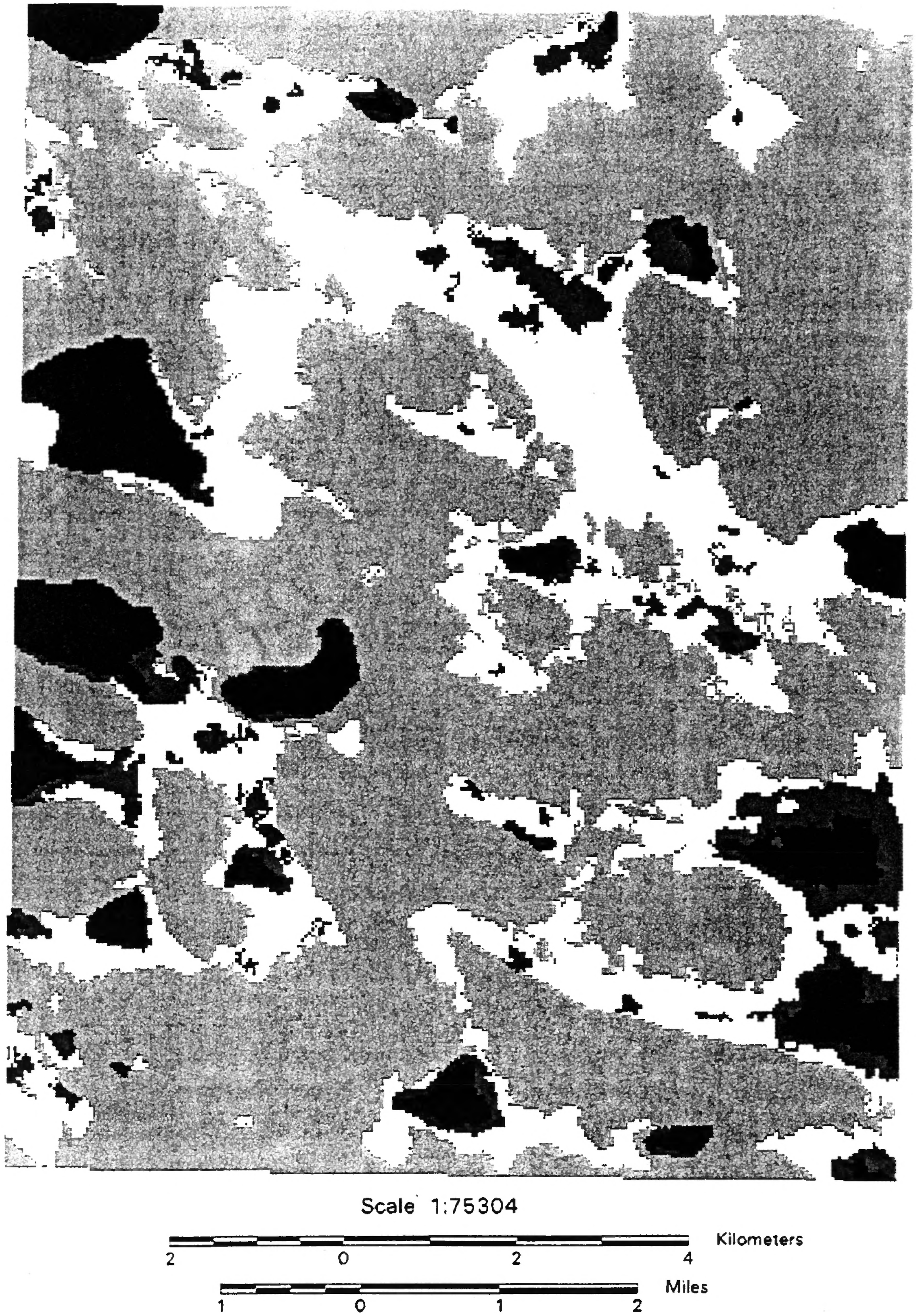

Figure 11. Wetland mapping results for 1972.

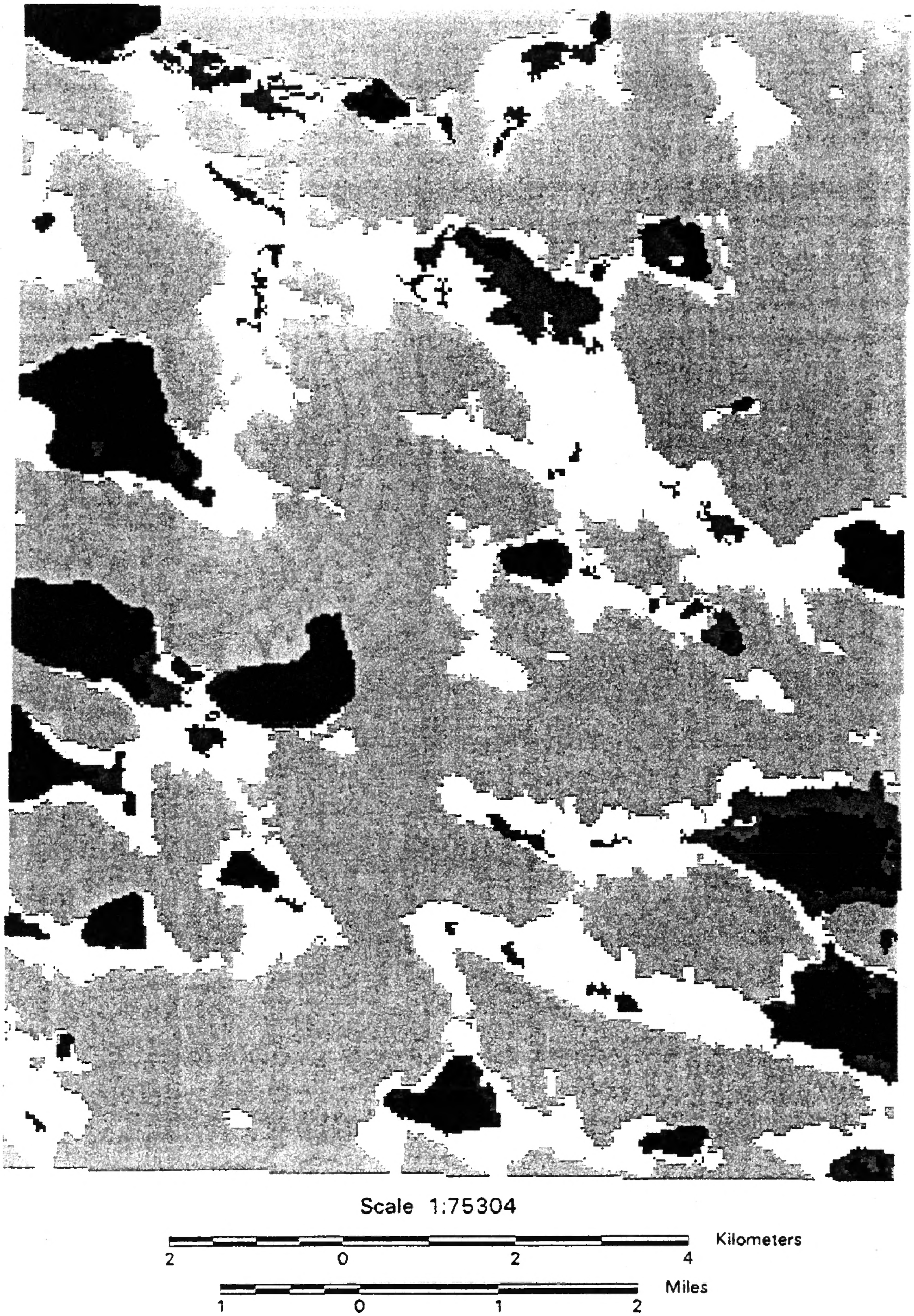

Figure 12. Wetland mapping results for 1975.

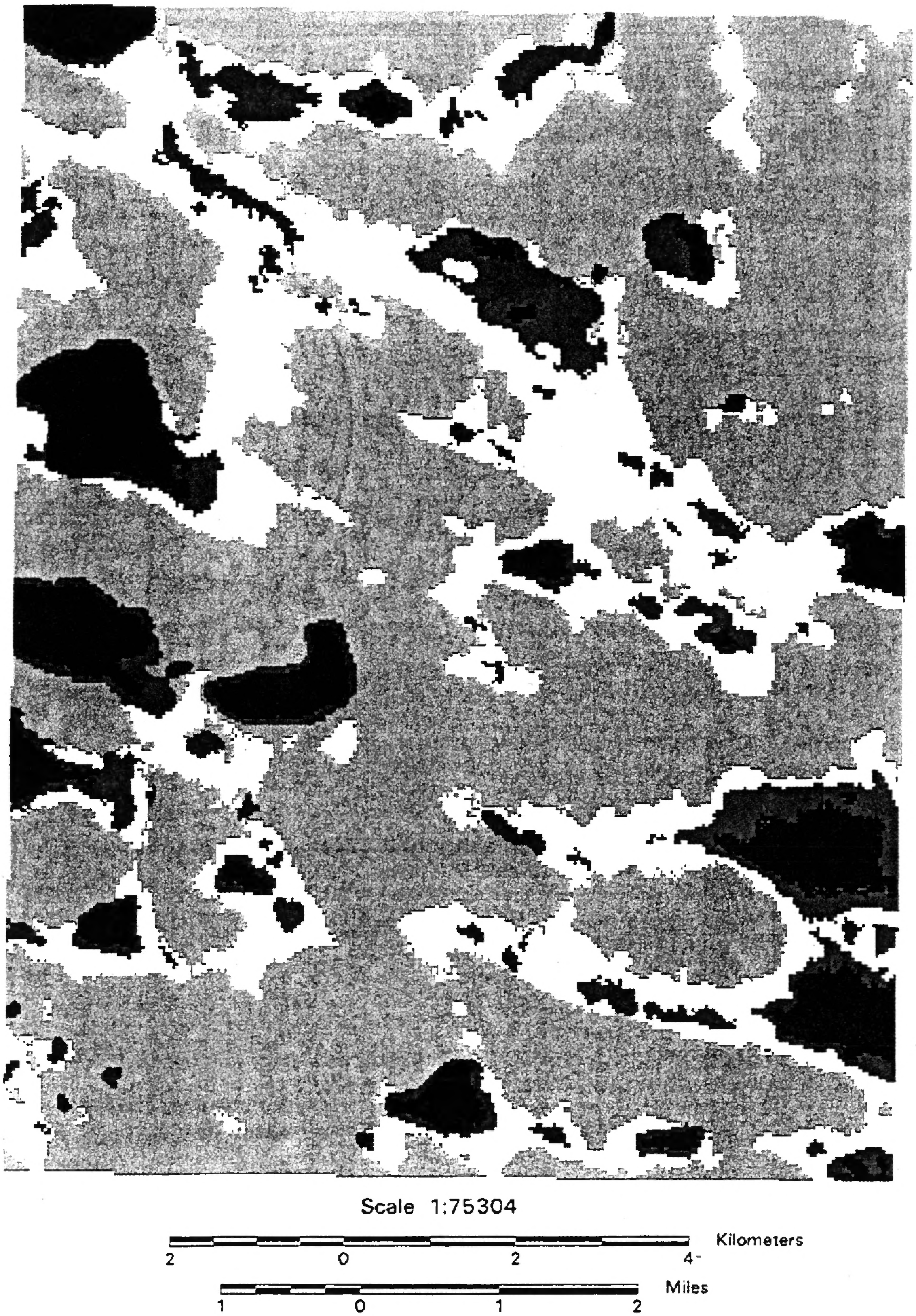

Figure 13. Wetland mapping results for 1978.

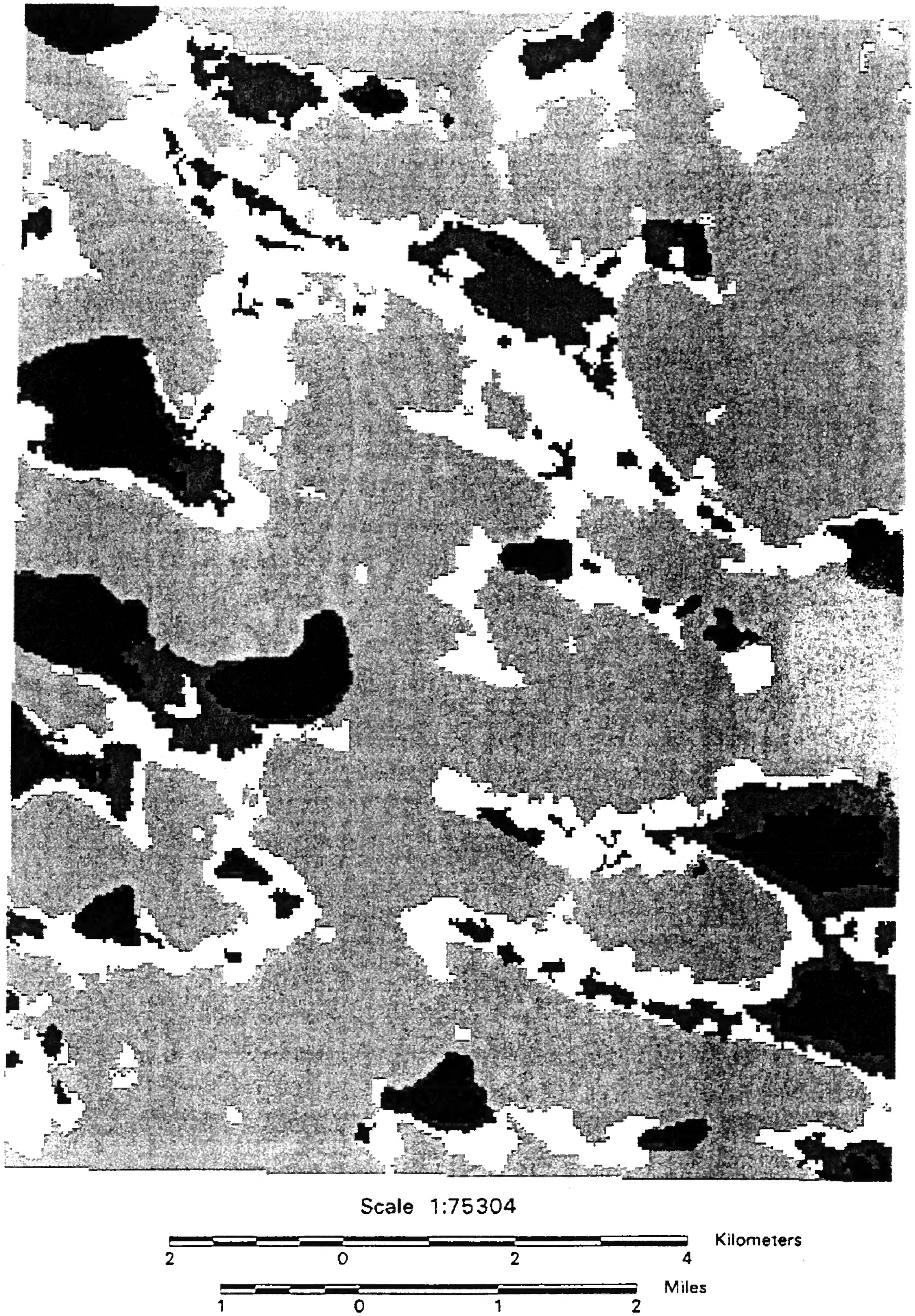

Figure 14. Wetland mapping results for 1979.

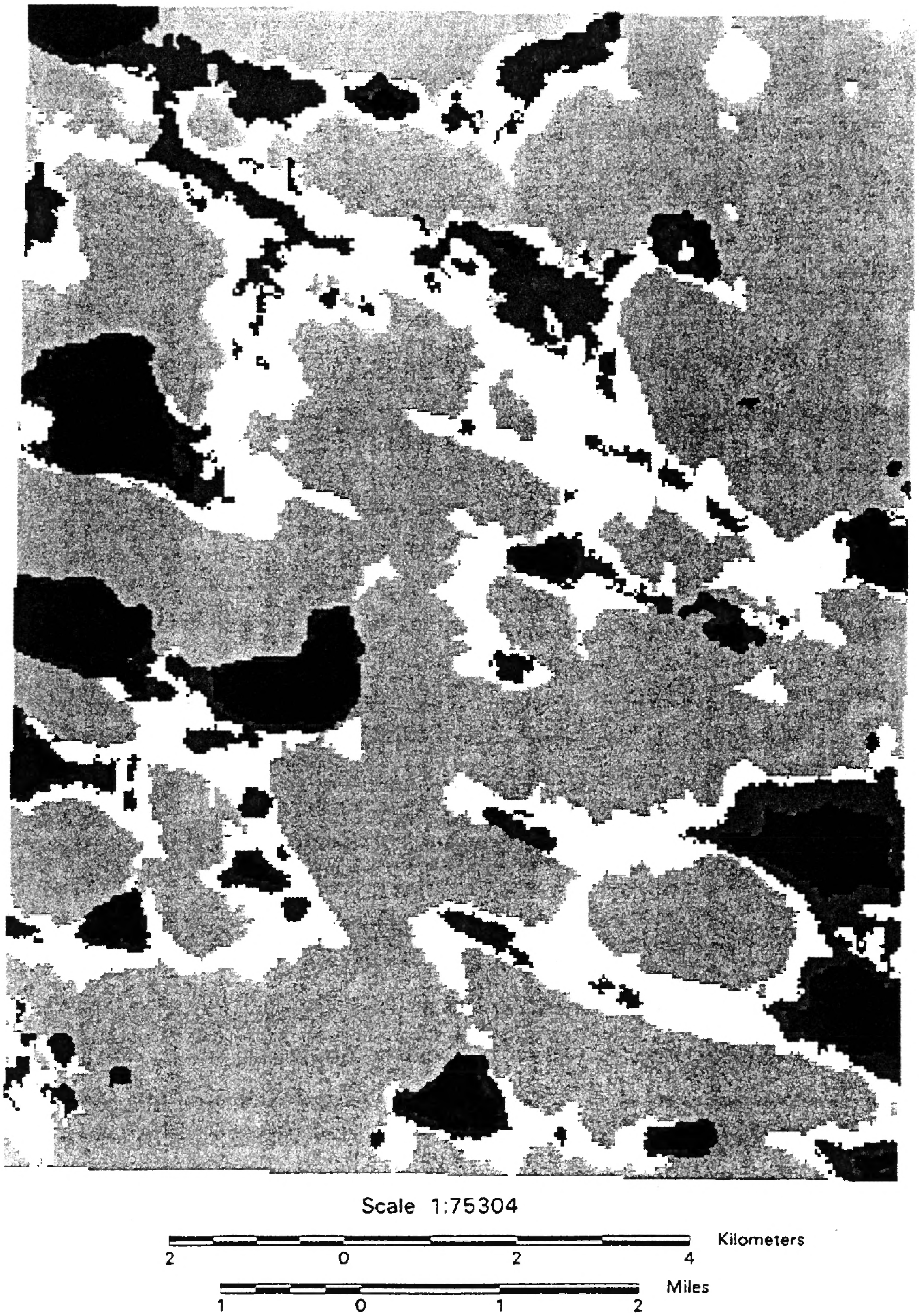

Figure 15. Wetland mapping results for 1982.

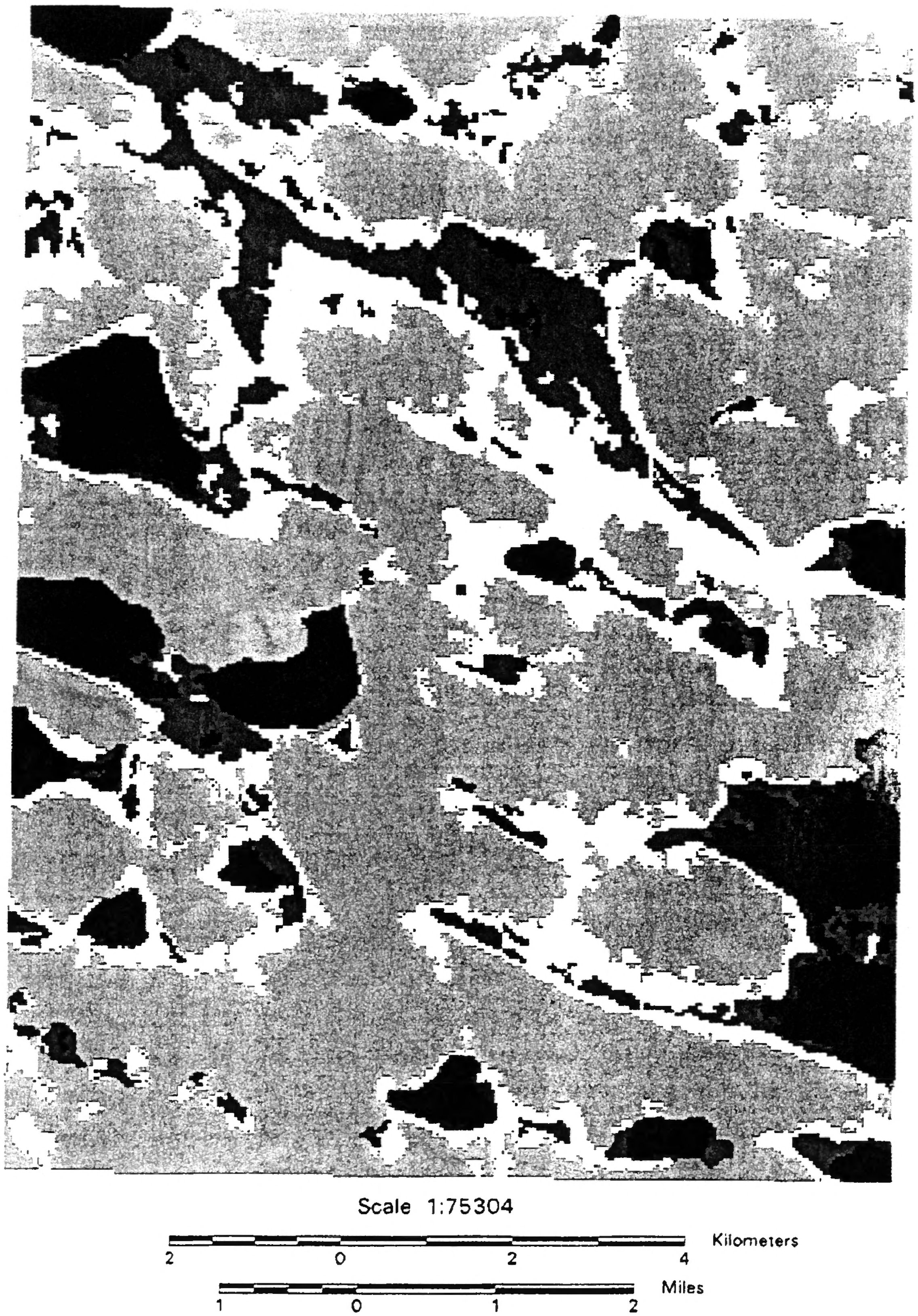

Figure 16. Wetland mapping results for 1984.

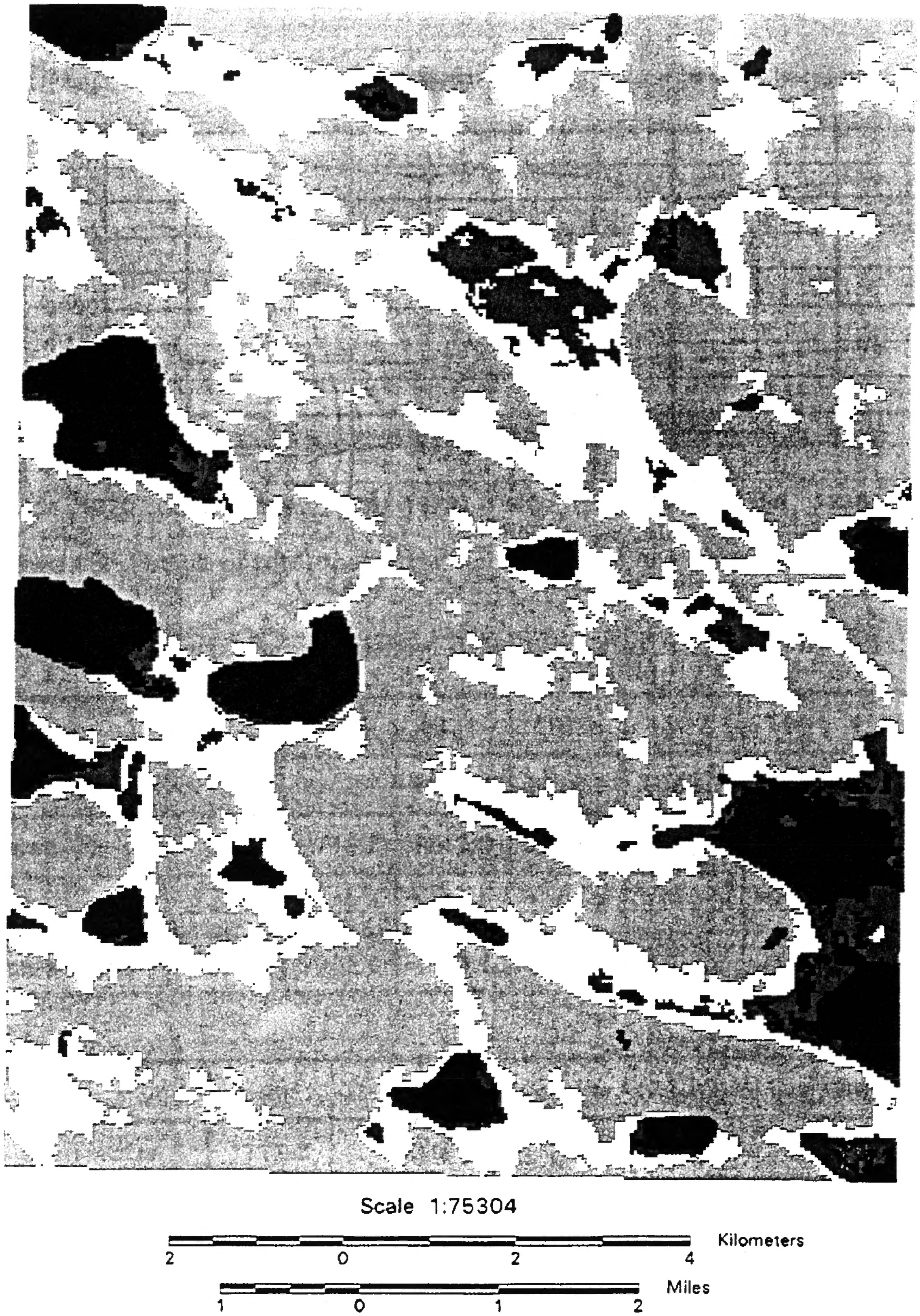

Figure 17. Wetland mapping results for 1989.

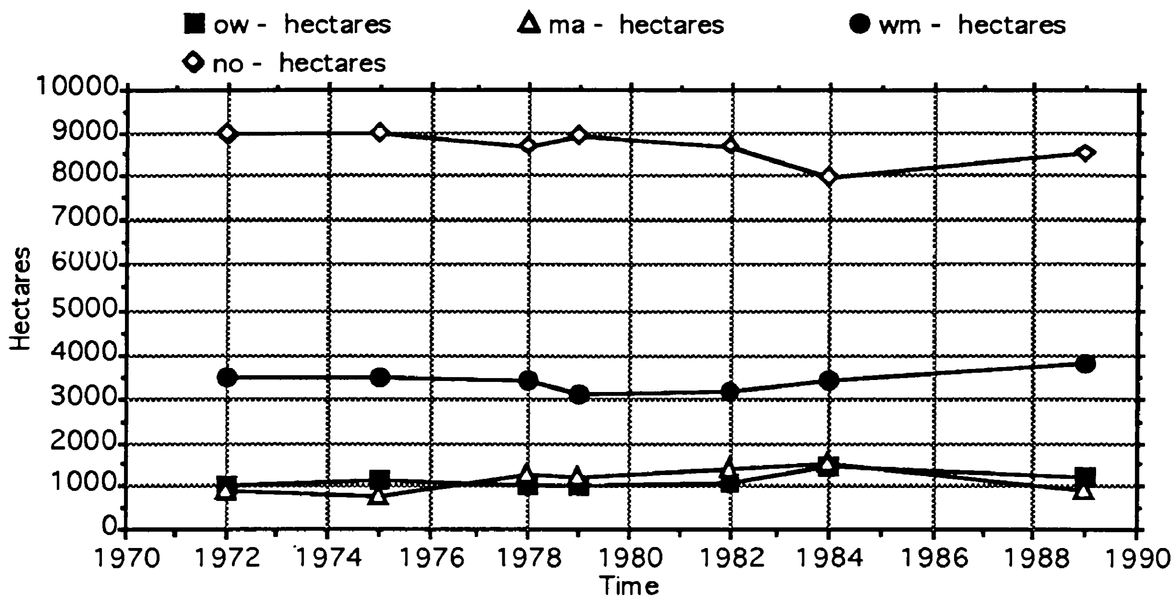

Figure 18. Graph of total measured hectares by class for study period.

Table 2. Total hectares by class and descriptive statistics of study area.

	1972	1975	1978	1979	1982	1984	1989
Open Water	967.0	1102.7	1002.4	1018.7	1048.3	1458.7	1185.0
Marsh	840.5	718.2	1241.0	1199.5	1396.3	1505.6	869.0
Wet Meadow	3483.7	3499.4	3405.6	3082.2	3149.0	3434.9	3780.0
Non-wetland	9012.2	9002.4	8673.1	8973.8	8708.8	7950.6	8488.8

	Mean	Stand. Dev.	Coef. Var.	(72,89)% Area Change
Open Water	1111.8	169.0	15.20	+ 22.53 %
Marsh	1110.0	302.2	27.22	+ 3.39 %
Wet Meadow	3404.8	88.1	6.85	+ 8.54 %
Non-wetland	8687.1	143.9	4.38	- 5.81 %

Figure 18. illustrates the measured changes in wetland classes over time; ow = Open Water, ma = Marsh, wm = Wet Meadow, and no = Non-wetland. Table 2 contains the results for each class measured in hectares, including some basic descriptive statistics for the study data.

In an absolute sense, the results indicate that there were increases in the total area of wetlands between 1972 and 1989. Non-wetland areas decreased in total area by 5.81%, while Marsh and Wet Meadow increased 3.39% and 8.54%, respectively. Open Water increased dramatically with an increase of 22.53%. But as Table 2 indicates, two of the classes, Marsh and Open Water, exhibited rather extensive variability across the seven samples with a coefficient of variance of 27.22% and 15.20%, respectively. Wet Meadow and Non-wetland varied only 6.85% and 4.38% over the study period.

Such high variability suggested that the seven samples might not produce statistically definitive conclusions. A simple regression test indicated that the data did not, in fact, trend linearly (Table 3) To support this hypothesis, a second-order polynomial regression was applied to the data, and the results confirmed that indeed, there was no linear trend, but the data did not seem to match the second-order curve either, suggesting a more complex transition over the study period (Table 3).

At this point, it was concluded that no statistically significant changes could be interpreted from the total area measurements of the seven samples gathered for the study. The data show that over the 17-year study period, wetland areas changed only slightly in overall size but that there was considerable variation from year to year. This seemed to suggest that more samples would be required (perhaps many more) to develop statistical conclusions about overall wetland trends in the study area. This also suggested that satellite data, alone, may not provide enough temporal information, or samples, to develop a definitive evaluation of wetlands in the study area, due to the short period of time that satellite imagery is available (1972 to the present).

Table 3. Regression results on total hectares, by class.

Simple Linear Regression

n = 7	R	R^2	Std. Err.	F
Open Water	.594	.353	148.91	2.73
Marsh	.363	.132	308.46	0.76
Wet Meadow	.277	.077	245.41	0.42
Non-wetland	.701	.491	297.52	4.83

2nd Order Polynomial Regression

n = 7	R	R^2	Std. Err.	F
Open Water	.598	.357	165.97	1.11
Marsh	.819	.671	212.20	4.08
Wet Meadow	.836	.699	156.65	4.65
Non-wetland	.714	.509	326.63	2.08

However, a look at how the wetlands changed from year to year, through an examination of the crosstabulation results for each, consecutive sample pair, revealed information about how each class varied during the study period (Table 5). Though seven samples were unlikely to indicate statistically significant results, the crosstabulation results provided more information about the characteristics of the area wetlands than simple, total measured results as previous surveys had done. This method also indicated the level of consistency of each class, from year to year, and what changes occurred between classes.

Over the entire study period, the Open Water areas seemed to stay fairly consistent 88.67% of the time. The Marsh areas displayed the most instability, changing spatially, 54.72% of the time. Wet Meadows remained stable 69.34% of the time, while Non-wetland areas were the most stable class at 90.69% (Table 4). A "measure of persistence" was developed that indicated the percent of each class that remained the same from the previous sample year, and indicated the continuity of each wetland class over time. This supported the earlier findings that while the total area of each class changed only slightly, high variability was exhibited by each class from sample period to sample period.

Table 4. Measure of persistence for each sample pair.

	72-75	75-78	78-79	79-82	82-84	84-89
open water	95.73	84.67	87.03	89.46	97.97	77.16
marsh	51.25	74.36	58.38	61.65	52.38	30.30
wet meadow	77.34	72.36	65.53	69.37	66.83	64.58
non-wetland	92.50	90.53	92.33	90.57	86.24	90.95

Table 5 lists the correlation for each class in hectares, by sample pair, and reflects the directions of changes that occurred between sample years; ow = Open Water, ma = Marsh, wm = Wet Meadow, no = Non-wetland. From this information it was possible to determine, on a sample pair by sample pair basis, if increases and decreases in each class were the result of sporadic changes or if there were definite shifts indicated in the coverage of each class from year to year.

Table 5. Crosstabulation results in hectares by class. First year data is represented in the rows, second year data is in the columns.

72vs75

	ow	ma	wm	no	Total
ow	925.76	32.96	2.88	5.44	967.04
ma	154.56	430.72	199.68	55.52	840.48
wm	3.84	196.00	2693.44	589.28	3482.56
no	17.44	58.56	600.32	8335.52	9011.84
Total	1101.60	718.24	3496.32	8985.76	

75vs78

	ow	ma	wm	no	Total
ow	928.00	142.40	9.60	16.00	1096.00
ma	53.92	531.36	92.80	36.48	714.56
wm	12.46	488.00	2527.68	464.80	3492.94
no	4.00	74.56	770.88	8121.12	8970.56
Total	998.38	1236.32	3400.96	8638.40	

78vs79

	ow	ma	wm	no	Total
ow	869.76	99.20	21.12	9.28	999.36
ma	120.32	723.68	298.56	96.96	1239.52
wm	4.48	271.52	2229.44	896.48	3401.92
no	24.16	105.12	533.12	7970.56	8632.96
Total	1018.72	1199.52	3082.24	8973.28	

79vs82

	ow	ma	wm	no	Total
ow	907.36	93.60	4.80	8.48	1014.24
ma	100.48	737.76	312.00	46.40	1196.64
wm	12.00	422.24	2134.24	508.16	3076.64
no	20.00	134.00	690.24	8113.76	8958.00
Total	1039.84	1387.60	3141.28	8676.80	

82vs84

	ow	ma	wm	no	Total
ow	1026.88	16.16	4.48	0.64	1048.16
ma	385.12	731.36	234.40	45.44	1396.32
wm	23.20	660.64	2104.48	360.64	3148.96
no	18.24	95.52	1084.48	7510.24	8708.48
Total	1453.44	1503.68	3427.84	7916.96	

84vs89

	ow	ma	wm	no	Total
ow	1121.44	290.24	35.52	6.24	1453.44
ma	56.96	455.68	920.16	70.88	1503.68
wm	1.44	98.72	2213.76	1113.76	3427.68
no	3.84	24.32	609.44	7279.04	7916.64
Total	1183.68	868.96	3778.88	8469.92	

From 1972 to 1975, the major change that occurred was a transition of some Marsh areas to Open Water areas. This is indicated by an approximate 14% increase in area for Open Water and a corresponding approximate 14.5% decrease in Marsh area. All other changes seemed to balance out between classes.

Between 1975 and 1978, the study area experienced a dramatic expansion of the Marsh class by approximately 73%. Most of the change was the transformation of Wet Meadow areas to Marsh, constituting about a 55% increase from this change alone. The other class that gave substantial ground was Open Water, adding another 12.5% to Marsh. At the same time, there was an indication of a slight expansion of Wet Meadow areas into Non-wetland areas. While the overall area of Wet Meadow did not increase in size, the numbers indicate that there was an overall expansion in wetland area between these two years.

Less extreme changes occurred in the study area between 1978 and 1979. Open Water and Marsh classes changed very little, and there was only a slight shift of Wet Meadow to Non-wetland, as approximately 10.5% of the Wet Meadow area was lost to the Non-wetland area. This resulted in Non-wetland areas increasing in area by approximately 4%.

From 1979 to 1982, the area seemed to transition toward more wetland area, as the percent gains versus percent losses indicated that the Non-wetland class lost more to Wet Meadow than it gained from Wet Meadow. Subsequently, the Wet Meadows class lost more to Marsh than it gained, and Marsh lost more to Open Water than it gained.

Between 1982 and 1984 there were major increases in the amount of Open Water present in the study area, and there was a considerable overall shift in wetland conditions. Open Water increased dramatically by about 39%, gaining primarily from Marsh areas, Marsh expanded by about 8%, gaining from Wet Meadow, and Wet Meadow areas grew by nearly 9% from expansion into what was previously Non-wetland.

Examination of the final sample pair, 1984 to 1989, suggested a reversal from the previous pair. There was an overall shift towards the Non-wetland class, with the most significant change occurring with Marsh areas becoming Wet Meadow. Just over 61% of the Marsh areas transformed into the class Wet Meadow, accounting for most all of the Marsh losses. For this period, the crosstabulation results indicate that wetland loss characterizes the the overall wetland condition.

To summarize the changes from 1972 to 1989, a crosstabulation analysis was performed between these two datasets (Table 6). The calculated "measure of persistence" for each class was Open Water 88.57%, Marsh 42.11%, Wet Meadow 67.53%, and Non-wetland 85.64%. Increases in Open Water, by almost 13%, were due to expansion into what were Marsh areas. Similarly, Marsh increases were due to expansion into the Wet

Meadow areas. However, the Marsh class exhibited a rather large amount of positional shift between the two years. While there were increases in the Marsh class between 1972 and 1989, over 57% of the Marsh class was located differently in 1989. Also, during this period, Wet Meadow expanded into Non-wetland areas by about 13%.

Table 6. Crosstabulation results for the years 1972 vs. 1989, in hectares.

72vs89	ow	ma	wm	no	Total
ow	856.48	96.96	9.60	4.00	967.04
ma	220.64	353.92	242.40	23.52	840.48
wm	59.20	346.88	2351.68	724.80	3482.56
no	47.52	71.20	1175.20	7717.92	9011.84
Total	1183.84	868.96	3778.88	8470.24	

DISCUSSION

The results of this study suggest that the determination of statistically significant wetland changes would require more samples than used here. The large, overall variability of class measurements demonstrated that a small number of samples (such as that used here, n=7) was perhaps not sufficient, and should not be interpreted or extrapolated into a definitive trend of changes. The results do indicate the conditions of the wetlands in the study area for the times sampled, and perhaps the variability should be interpreted as a reflection of the natural variability of sandhill wetlands from year to year. Determining a trend in these wetlands may be similar in nature to defining a drought, where the question is what duration and what deviation from normal constitutes a drought. In sandhill wetlands, what changes are significant and how long must they be sustained to indicate a trend of change? Future temporal studies should explore this question more closely to gain a better insight on this issue. Determination of the causes of year-to-year changes is beyond the scope of this study, but could be related to groundwater levels, climate patterns, pollution, and management practices.

With the availability of high frequency, mapping information from satellite data, and the advances in computer technology and software, more in-depth temporal analyses could be performed. It is quite probable that at least one satisfactory image could be acquired for each year since 1972, and this same analysis approach used to map wetlands. Such a study would likely provide a more informative representation of wetland changes. However, until recently, historical satellite imagery was rather expensive and the acquisition of 20+ images was, in all practicality, out of the question. Since EOSAT (as of 1993) has lowered its prices for archived, historic data, the financial possibility for such a project is much more plausible.

One of the more difficult issues of a temporal analysis of sandhill wetlands is the problem of selecting image data that adequately represent wetlands. In this study, the problem was to determine if the wetlands were changing in a discernible fashion. Data selection focused on peak growing season, late spring to early summer, as describe by Rundquist and Linden (1979). Perhaps this time of year experiences more year-to-year variation than another time. Previous studies have indicated that as the summer season progresses, evapotranspiration rates increase with the warmer temperatures, resulting in a reduction of open water in marsh zones

(Buckwalter, 1983, Rundquist et al., 1987). Perhaps a different time of year would represent annual wetland conditions with less between year variation. Research is needed to define the best time of year to gather remotely sensed data for the most dynamic representation of wetland conditions.

Though the crosstabulation results were not statistically analyzed, Table 4 illustrates the changes that occurred during the study period, quite well. What is most apparent from the "persistence" measures of this study, is that the Marsh and Wet Meadow class seem to vary more than the Open Water and Non-wetland classes. This seems to correlate well with the findings of Frolik and Keim, 1933; Tolstead, 1942; Ehlers et al., 1952; Brouse and Burzlaff, 1968; that the depth to water table is an important factor in controlling vegetative structure in wet meadows. It makes sense that the areas between both extremes (open water to dry, xerophyte covered sand dunes) would exhibit the most change.

The ability to perform a spatial correlation over time, could produce some interesting results. If separate wetlands could be monitored, with sufficient temporal sampling, not only would changes be detectable, but the magnitude and tendency of change could be measured as well. Analysis models could be constructed to more definitively delineate "core" wetland areas (or areas of a wetland with high persistence) versus fluctuating transitional areas, providing a better, overall understanding of the long term environmental changes of these wetlands.

The low measures of persistence for Marsh and Wet Meadows suggested that ecological habitat might have changed as well. As stated previously, direct comparison of 1972 data versus 1989 data indicated that only 42% of the Marsh class was located where it started in 1972. The area experienced an overall increase in Marsh areas, but what does this imply about habitat changes? Answering ecological questions about sandhill wetlands is beyond this study, but the utility of this study is perhaps best demonstrated in this discussion of habitat. While satellite data is not an adequate data source for detailed wetlands mapping, it is well suited for targeting areas where further investigation may be necessary, as demonstrated by this example.

In this study, a procedure was presented that compared wetland information produced from both MSS and TM satellite imagery. In doing so the potential existed for variation to manifest itself in the mapping results, due to the differences between these sensors. Much of this problem was avoided by the procedures used in the preprocessing and classification steps. The spatial resolution of both data types were resampled to 40 m x 40 m cells. This was done to allow for direct comparison, necessary for spatial correlation in the crosstabulation analysis. Applying this process to the datasets should have changed the data very little, as the algorithm used in the ERDAS software uses an approach similar to algorithms used in terrain modeling. Pixels were treated as samples of the overall, continuous surface, the smaller cell size was produced by interpolating the spectral reflectance between the known pixel values.

The classification methodology focused on extracting the most wetland information from both sensors. The steps followed, were similar to those used by Koeln et al. (1986), which demonstrated wetland mapping from TM data. The methods used in this study tested MSS data against CIR photography and showed good mapping accuracies. Overall, the mapping procedures that were followed performed well, and outlined a technique to maximize temporal wetland information that can be derived from satellite imagery.

The inability to use NWI information in this project was disappointing. Three primary factors precluded direct use of the data. First, the photography used to delineate wetlands in this area was gathered in April 1982. This time frame is probably too early to capture a true representation of the wetland conditions (Rundquist and Linden, 1979). Several major discrepancies were evident in comparing the 1979 CIR photos. There were some NWI areas labeled as marsh vegetation, that were being hayed in 1979, based on the CIR (Marsh areas seldom contain vegetation that is worth haying). Another important issue was the fact that NWI was photo-interpreted from CIR photography, for the purpose of identifying ecological habitat (Cowardin et al., 1979). The example in the Accuracy Assessment section of chapter 2 illustrates a good example of the inability of satellite data to produce the same level of spatial detail of aerial photography. Consequently, the information that is most important in satellite data for most resource mapping is the spectral signature of the target. The discussion in the last part of the Preprocessing section about spectral confusion between alkaline lakes and upland dune slopes, is a good example of the importance of spectral separability of the surface features to be mapped. Without the addition of the NDVI transformation it was apparent that most alkaline lakes would have have been represented as Non-wetland.

The last reason NWI was not directly used was because the data was only available in hardcopy form. It was deemed unreasonable to have attempted to digitize the map data. However, it would have been interesting to see the results of a spatial correlation of the satellite results with the NWI map data.

Chapter Four: Conclusions and Recommendations

This study is an extension of previous remote sensing studies of sandhill wetlands. Satellite data has long been accepted in mapping and monitoring wetlands in the sandhills of Nebraska. The results of this study reaffirm this, and suggest an additional approach that allows for the comparison of Landsat MSS and TM derived wetland information.

A methodology was presented that examined wetland mapping results from MSS and TM satellite imagery. Though previous studies have demonstrated the ability of each sensor to map wetlands, the results for these studies were not intended for direct comparison. The major difference between the two sensors, as far as wetlands are concerned, is the ability of the TM sensor to define sub-marsh categories, more specifically, the Deep Marsh and Shallow Marsh classes, as defined in this study. Koeln et al., (1986) found that the added spatial resolution and the moisture identification abilities of the mid-infrared bands, on the TM platforms, provided a unique advantage over the older MSS platforms. This advantage allowed them to successfully distinguish these two types of marsh. This might lead one to believe that TM data would be the preferred sensor, but doing this would ignore 10 years of wetland information that could be derived from MSS. The use of MSS in association with TM for mapping wetlands over time, as has been demonstrated here, provides a more long-term perspective in understanding how this resource has changed over time.

The image analysis steps were designed specifically to address the need to examine temporal changes in wetlands using the two sensors. Temporal studies typically include analysis of historical data rather than anticipative data, which precludes the gathering of associated field data. The methodology presented was designed to be repeatable with the assumption that some reference data are available (e.g., CIR photography, NWI map data, or appropriate, previously gathered data of the study area), the analyst has knowledge of general remote sensing techniques and techniques in remote sensing of wetlands, and some general knowledge of the sandhills.

The datasets used, were not sufficient to determine a statistically conclusive trend in wetland changes, if indeed one existed. The results indicated a high degree of variability within some of the wetland classes, over time. The nature of the variability may suggest the need for more data samples or may simply demonstrate the natural fluctuations in sandhill wetlands. Spatial correlation analysis of wetland mapping results has provided an informative perspective on wetland changes. The "measure of persistence" suggested more definitively, the variability of each wetland class than could be determined from area measurement totals. The use of spatial correlation in general is an expansion of previous work in mapping wetlands in the sandhills. Previous studies have concentrated either on overall changes in wetland area or have focused on specific wetland characteristics or types.

The results of this study reflected wetland conditions as well as was possible to determine from satellite data. Results such as these may have their strongest utility in the area of resource management. Since the data is based upon digital analysis, it is easily compatible with geographic information systems (GIS), and can be repeated as needed. This information could be used to identify areas of major change, for identifying locations where additional or field evaluation is needed, or for environmental impact studies.

The importance of the wetlands of the sandhills lies in their abundant wildlife habitat, rich valleys for haying and livestock forage, and also as an area of groundwater recharge. Through examination of satellite imagery over time, we have the ability to regularly monitor the conditions of sandhill wetlands. This information may be used as a management tool or as an indicator of the need for further investigation. A better understanding of the dynamics and types of changes that occur in these wetlands, may help us preserve and wisely manage this valuable natural resource.

Literature Cited

Barnes, P. W. and A. T. Harrison. 1982. "Species Distribution and Community Organization in a Nebraska Sandhills Mixed Prairie as Influenced by Plant/Soil-water Relationships. *Oecologia* 52:192-201.

Bleed, Ann. 1989. "Groundwater." in *An Atlas of the Sandhills.* Resource Atlas No. 5. Conservation and Survey Division. University of Nebraska-Lincoln.

Brouse, E. M, and D. F. Burzlaff. 1968. *Fertilizers and Legumes on Subirrigated Meadows.* University of Nebraska Agriculture Experiment Station Bulletin No. 501. University of Nebraska-Lincoln.

Buckwalter, Donald W. 1983. *Monitoring Nebraska's Sandhills Lakes.* Resource Report No.10. Conservation and Survey Division. University of Nebraska-Lincoln.

Christian, Donald R., Jr. 1983. *Monitoring Subirrigated Meadow Loss in the Nebraska Sandhills Using Remote Sensing Techniques and Theory.* Final Report of a Project Conducted under the NASA University Affairs Program, Grant #NGL 28-004-020.

Cihlar, J., L. St.-Laurent, and J. A. Dyer. 1991. "Relation Between the Normalized Difference Vegetation Index and Ecological Variables." *Remote Sensing of the Environment.* 35:279-298.

Congalton, Russel G. 1991. "A Review of Assessing the Accuracy of Classifications of Remotely Sensed Data." *Remote Sensing of the Environment.* 37:35-46.

Cowardin, Lewis M., Virginia Carter, Francis C. Golet, and Edward T. LaRoe. 1979. *Classification of Wetlands and Deepwater Habitats of the United States*. Biological Services Program. U.S. Fish and Wildlife Service. U.S. Department of the Interior. U.S. Government Printing Office.

Dreeszen, Vince. 1984. "Overview of Nebraska and the Sandhills" in *1984 Water Seminar Series: The Sandhills of Nebraska -- Yesterday, Today, and Tomorrow*. Nebraska Water Resources Center. University of Nebraska-Lincoln.

Ehlers, P. G., G. Viehmeyer, R. Ramig, and E. M. Brouse. 1952. *Fertilization and Improvement of native Subirrigated Meadows in Nebraska*. University of Nebraska-Lincoln Agriculture Experiment Station Circular 92. University of Nebraska-Lincoln.

ERDAS. 1990. *Field Guide*. Atlanta, Georgia.

Ernst-Dottavio, C. L., Roger M. Hoffer, and Richard P. Mroczynski. 1981. "Spectral Characteristics of Wetland Habitats." *Photogrammetric Engineering and Remote Sensing*. 47:223-227.

Frolik, A. L. and F. D. Kiem. 1933. "Native vegetation in the Prairie Hay District of North-Central Nebraska." *Ecology* 14:298-305.

Gilmer, David S., Ed A. Work, John E. Colwell, and Diana L. Rebel. 1980. "Enumeration of Prairie Wetlands with Landsat and Aircraft Data." *Photogrammetric Engineering and Remote Sensing*. 46:631-634.

Gilbert, Michael C. 1980. *A Technique for Evaluating Nebraska Sandhills Wetlands*. Master's Thesis, University of Nebraska-Omaha.

Gilbert, Michael C., Michael W. Freel, and Andrew J. Bieber. 1980. *Remote Sensing and Field Evaluation of Wetlands in the Sandhills of Nebraska*. Omaha: Regulatory Branch, U.S. Army Corps of Engineers.

Jacobson, J.E., R.A. Ritter, and G.T Koeln. 1987. "Accuracy of Thematic Mapper Derived Wetlands as Based on National Wetland Inventory Data." from ASPRS/ACSM/WFPLS 1987 Fall Convention. Reno, Nevada.

Jensen, John R. 1986. *Introductory Digital Image Processing: A Remote Sensing Perspective*. Prentice-Hall. Englewood Cliffs, New Jersey.

Keech, C.F. and Ray Bentall. 1971. *Dunes on the Plains: The Sand Hills Region of Nebraska.* Resource Report No. 4. Conservation and Survey Division. University of Nebraska-Lincoln.

Koeln, Greg T., David E. Wesley, Patrick J. Caldwell, and J.E. Jacobson. 1986. "Inventory of Wetlands with Landsat's Thematic Mapper." in *Proceedings of the 10th Canadian Symposium on Remote Sensing.* Edmonton, Alberta. 153-162.

Kuzila, Mark. 1989. "Soil Associations and Series." in *An Atlas of the Sandhills.* Resource Atlas No. 5. Conservation and Survey Division. University of Nebraska-Lincoln.

Lillesand, Thomas M. and Ralph W. Kiefer. 1987. *Remote Sensing and Image Interpretation.* John Wiley and Sons, Inc. New York, New York.

Mahoney, D. L. 1977. *Species Richness and Diversity of Aquatic Vascular Plants in Nebraska with Special Reference to Water Chemistry Parameters.* Mater's Thesis, University of Nebraska-Lincoln.

McAtee, W. L. 1941. *Wild Duck Foods of the Sandhills Region of Nebraska.* U.S. Department of Agriculture Bulletin No. 794. Washington, D.C. Government Printing Office.

McMurtrey, M.S., Robert Craig, and George Schildman. 1972. *Survey of Habitat, Nebraska Wetlands Survey.* Work Plan K-71. Pittman-Robertson Project W-15-R-28. Nebraska Game and Parks Commission.

Miller, Susan M. 1989. "Land Development and Use." in *An Atlas of the Sand Hills.* Resource Atlas No. 5. Conservation and Survey Division. University of Nebraska-Lincoln.

Novacek, Jean M. 1989. "The Water and Wetland Resources of the Nebraska Sandhills." in *Northern Prairie Wetlands.* Iowa State University Press. Ames, Iowa. Edited by Arnold van der Valk. pp. 340-384.

Pool, R. J. 1914. *A Study of the Vegetation of the Sandhills of Nebraska.* University of Minnesota Botanical Studies 4:189-312.

Rohde, Wayne G. 1978. "Digital Image Analysis Techniques Required for Natural Resource Inventories." from the *Proceedings of the National Computer Conference.* pp. 93-106.

Rouse, J. W., Haas, R. H., Schell, J. A., and Deering, D. W. 1973. "Monitoring Vegetation Systems in the Great Plains with ERTS." Third ERTS Symposium. Vol. 1.

Rundquist, Donald C. 1984. *Wetland Inventories of Nebraska's Sandhills*. Resource Report No.9. Conservation and Survey Division. University of Nebraska-Lincoln.

Rundquist, Donald C., Merlin P. Lawson, Lloyd P. Queen, Randall S. Cerveny. 1987. "The Relationship Between Summer-Season Rainfall Events and Lake-Surface Area." *Water Resources Bulletin*. 23:493-508. University of Nebraska-Lincoln.

Rundquist, Donald C. and Jeffrey S. Linden. 1979. *Toward a Digital Classification of Wetlands in the Nebraska Sandhills Region: A Test of Landsat MSS Data*. Final Report of a Project Sponsored by The Charles A. Lindbergh Fund, Inc. New York, New York.

Rydberg, P. A. 1895. *Flora of the Sandhills of Nebraska*. Contributions, U.S. National Herbarium, Volume 3, pp. 112-148.

Sather, J. H. 1958. "Biology of the Great Plains Muskrat in Nebraska." *Wildlife Monograph* 2.

Seevers, P.M., R.M. Peterson, D.J. Mahoney, D.G. Maroney, and D.C. Rundquist. 1975. "An Inventory of Nebraska Wetlands with the Use of Imagery from the Earth Resources Technology Satellite." in *Proceedings, Fourth Annual Remote Sensing of Earth Resources Conference*. University of Tennessee Space Institute. Tullahoma, Tennessee. pp. 281-292.

Swinehart, James B. and R.F. Diffendal, Jr., 1989. "Geology of the Pre-Dune Strata." in *An Atlas of the Sandhills*. Resource Atlas No. 5. Conservation and Survey Division. University of Nebraska-Lincoln.

Tiner, Ralph W., Jr. 1984. *Wetlands of the United States: Current Status and Recent Trends*. U.S. Fish and Wildlife Service. National Wetlands Inventory.

Tolstead, W. L. 1942. "Vegetation of the Northern Part of Cherry County, Nebraska." *Ecological Monographs* 12:255-292.

Turner, Jeffrey K. and Donald C. Rundquist. 1980. *Wetlands Inventory of the Omaha District*. Final Report. Contract Number DACW-45-79-C-0019. U.S. Army Corps of Engineers.

U.S. Department of the Interior. 1955. *Wetlands Inventory of Nebraska*. Published by the U.S. Fish and Wildlife Service. Office of River Basin Studies. Billings, Montana.

Wilen, Bill O. and Ralph W. Tiner, Jr. 1989. *The National Wetlands Inventory - The First Ten Years*. American Water Resources Association. GPO. Washington, D.C.

Wilhite, Donald A. and Kenneth G. Hubbard. 1989. "Climate." in *An Atlas of the Sandhills*. Resource Atlas No. 5. Conservation and Survey Division. University of Nebraska-Lincoln.

Work, Edgar A., Jr. and David S. Gilmer. 1976. "Utilization of Satellite Data for Inventorying Prairie Ponds and Lakes." *Photogrammetric Engineering and Remote Sensing*. 42:685-694.